Physics with the PHENIX Muon Arms
J/ψ's, charm and forward hadrons

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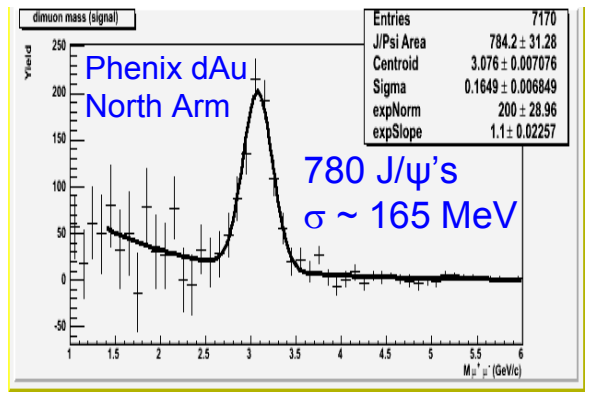
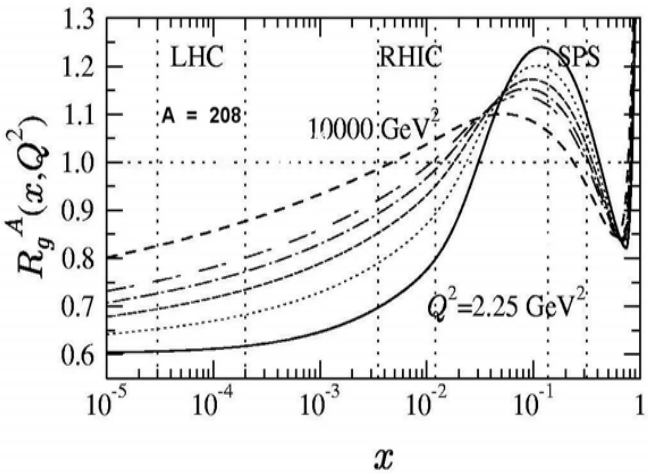
- Heavy-quark physics issues from pp and dAu towards AuAu
  - shadowing, p_T broadening, …
- The PHENIX muon arms
- J/ψ results from PHENIX
- Centrality dependence for J/ψ's
- Open Charm- another window complementary to J/ψ's
- Forward/backward hadrons from single muons
- Expectations for AuAu based on dAu results
- Other future physics focuses
- Summary



Nuclear modification of parton level structure & dynamics

Modification of parton momentum distributions of nucleons embedded in nuclei

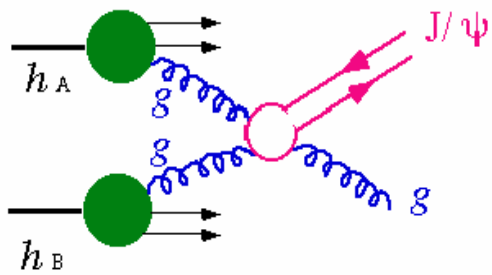
Eskola, Kolhinen, Vogt hep-ph/0104124



- e.g. shadowing – depletion of low-momentum partons
- Very low momentum fraction partons have large size, overlap with neighbors, and fuse; thus enhancing the population at higher momenta at the expense of lower momenta
- color glass condensate – specific/fundamental model that gives gluon shadowing in nuclei

Production of heavy vector mesons, e.g. J/Ψ,Ψ' and ϒ

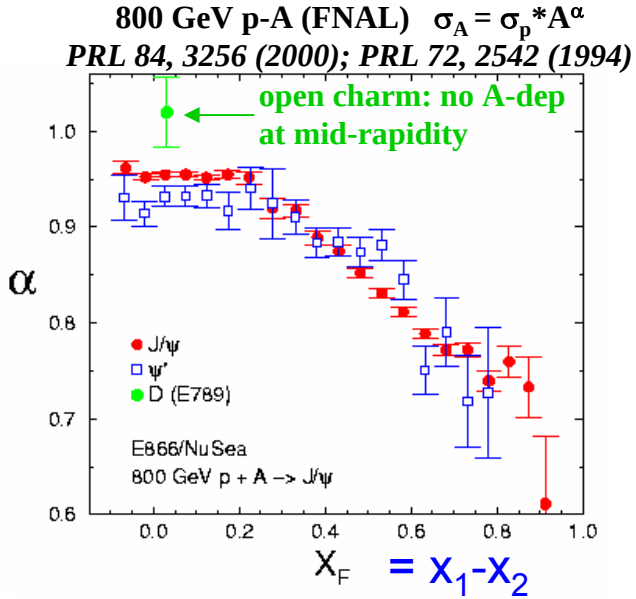
- production: color singlet or octet ccbar?
- hadronization time
- feed-down from higher mass resonances, e.g. χ_c



Nuclear modification of parton level structure & dynamics II

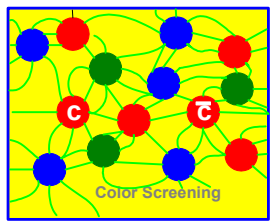
Nuclear effects on parton "dynamics"

- energy loss of partons as they propagate through nuclei
- and (associated?) multiple scattering effects (Cronin effect)
- absorption of J/ψ on nucleons or co-movers; compared to no-absorption for open charm production

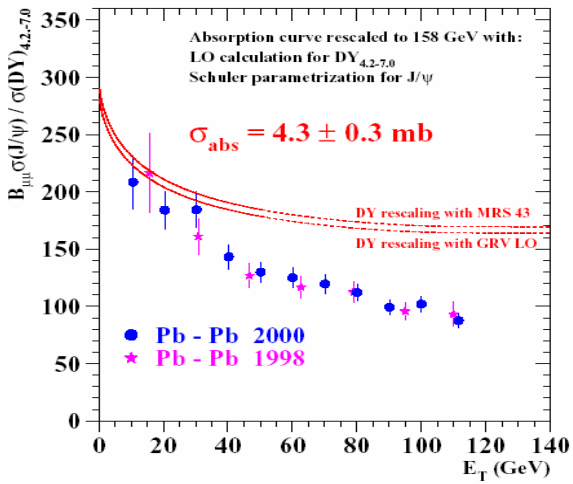


dAu also baseline for AuAu J/ψ Quark Gluon Plasma (QGP) signature

- Debye screening predicted to destroy J/ψ's in a QGP



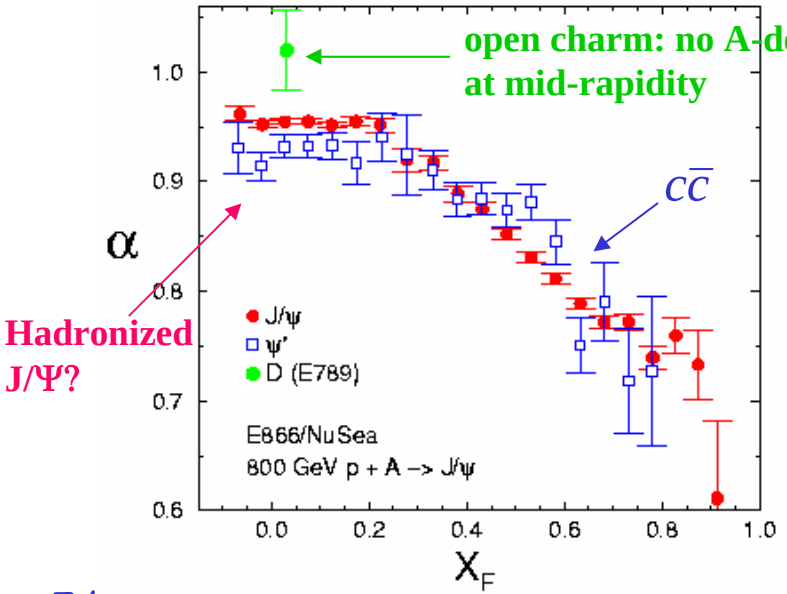
- but recent charm recombination models might instead cause an enhancement?



J/ψ suppression in pA fixed-target

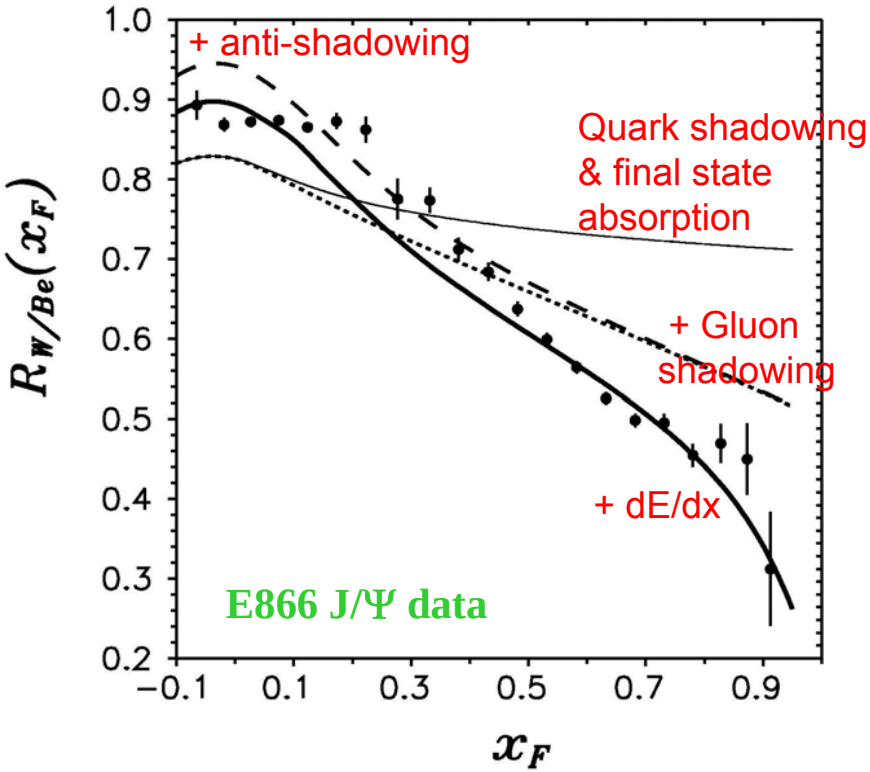
800 GeV p-A (FNAL)

Leitch et al, PRL 84, 3256 (2000); PRL 72, 2542 (1994)

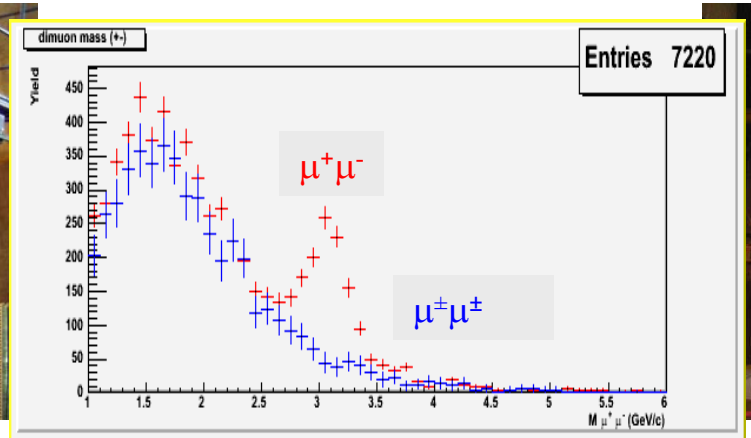


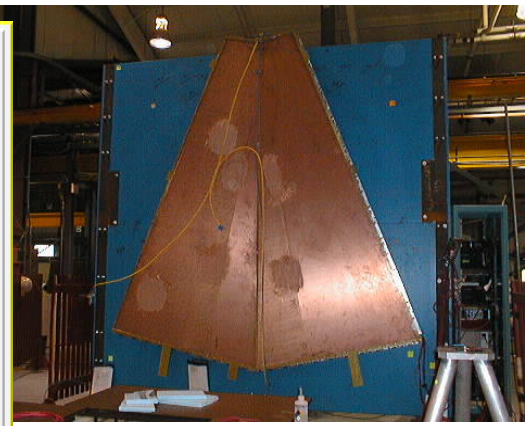
- J/Ψ and Ψ' similar at large x_F where they both correspond to a $c\bar{c}$ traversing the nucleus
- but Ψ' absorbed more strongly than J/Ψ near mid-rapidity (x_F ~ 0) where the resonances are beginning to be hadronized in nucleus
- open charm not suppressed (at x_F ~ 0)

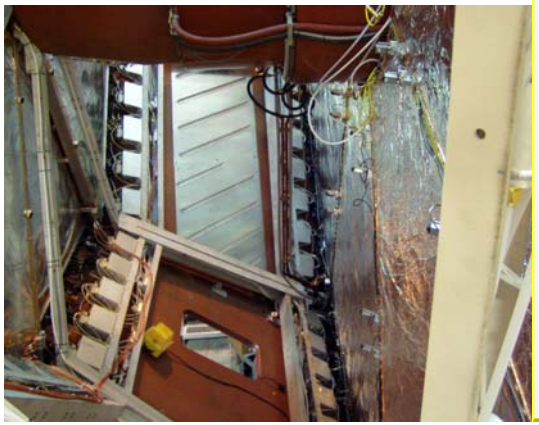
*Kopeliovich, Tarasov, Hufner
Nucl Phys A696 (2001) 669-714

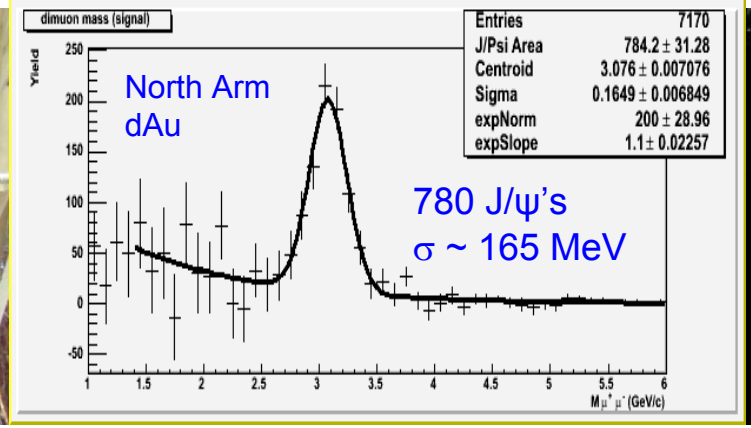


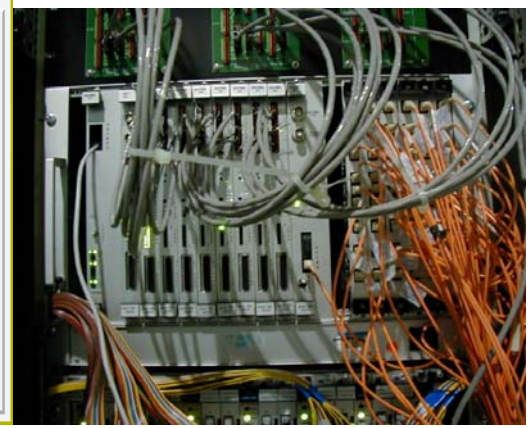
PHENIX Muon Arms designed, built, commissioned and maintained by Los Alamos with help from ORNL, PHENIX France, UNM, NMSU, Japan, Korea and others







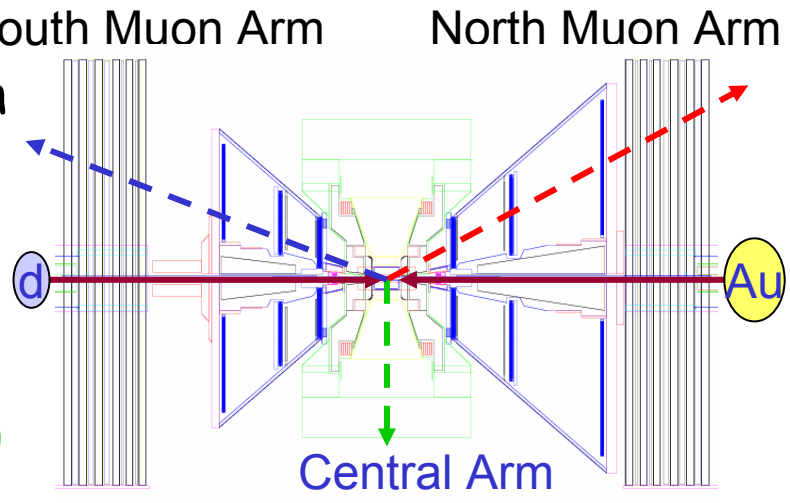




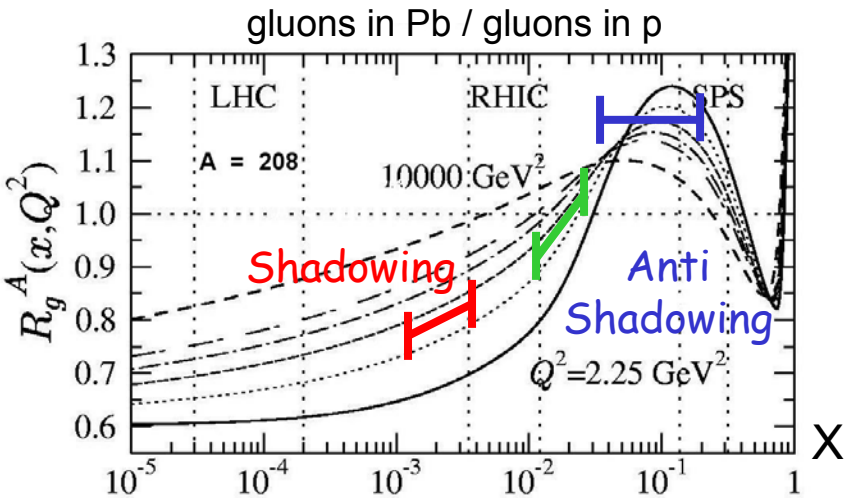
J/ψ → μ+μ- Analysis for dAu & pp

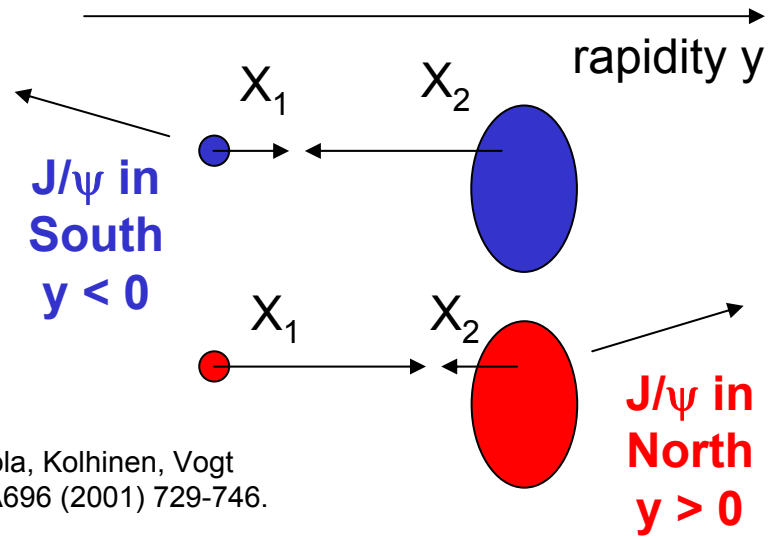
Analysis led by LANL (Mike Leitch)

- In PHENIX, J/ψ mostly produced by gluon fusion, and thus sensitive to gluon pdf
- Three rapidity ranges probe different momentum fraction of Au partons
  - South (y < -1.2) : large X_2 (in gold) ~ 0.090
  - Central (y ~ 0) : intermediate X_2 ~ 0.020
  - North (y > 1.2) : small X_2 (in gold) ~ 0.003



Example of predicted gluon shadowing in d+Au





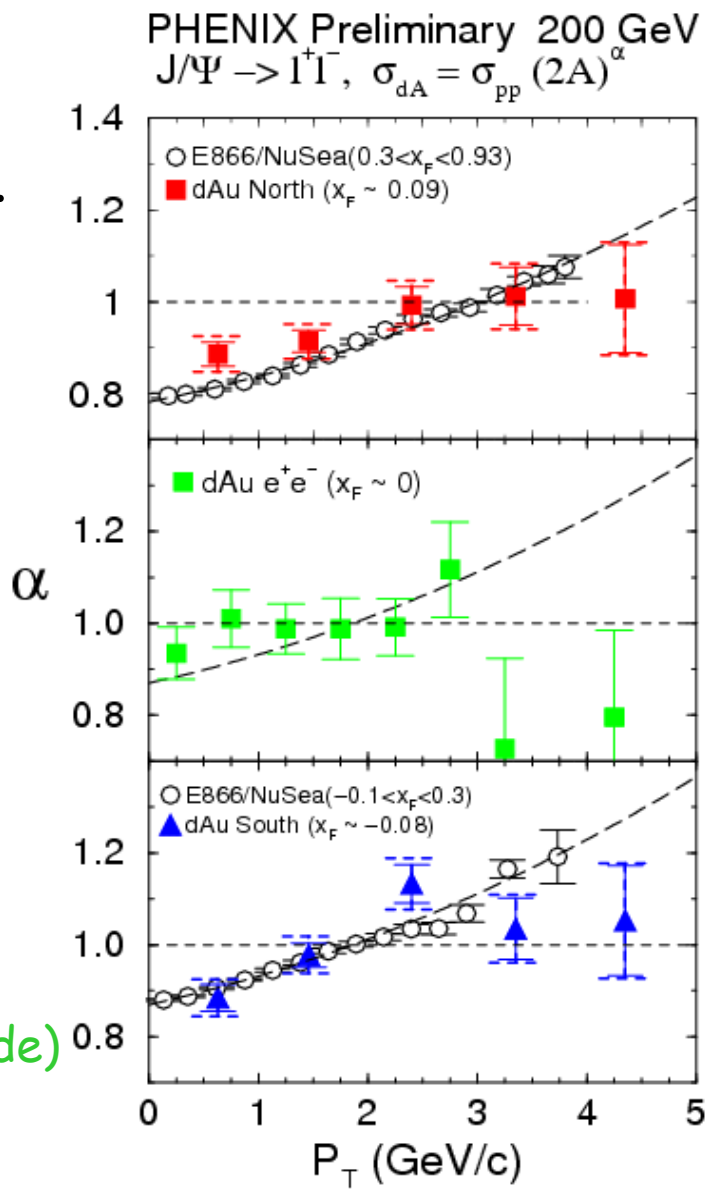
From Eskola, Kolhinen, Vogt
Nucl. Phys. A696 (2001) 729-746.

dAu/pp versus p_T

p_T broadening comparable to lower energy
($\sqrt{s}$ = 39 GeV in E866)

$$\sigma_{dA} = \sigma_{pp}\left(2\times 197\right)^{\alpha}$$

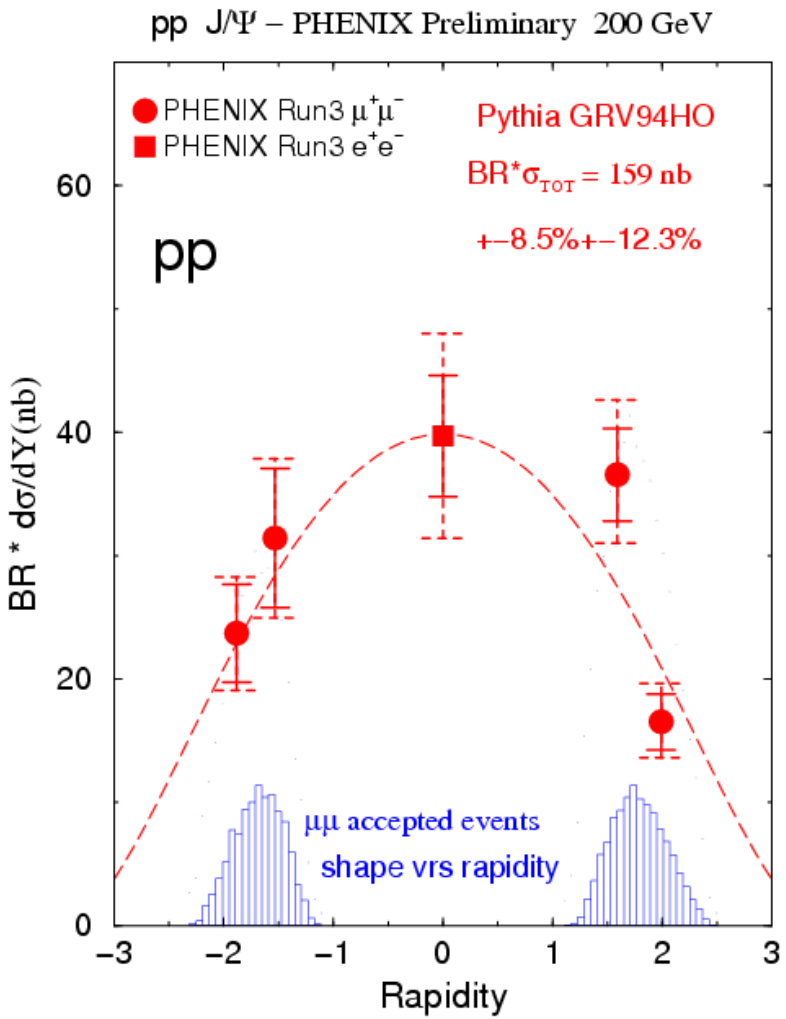
e^+e^- analysis led by Xie Wei (Riverside)

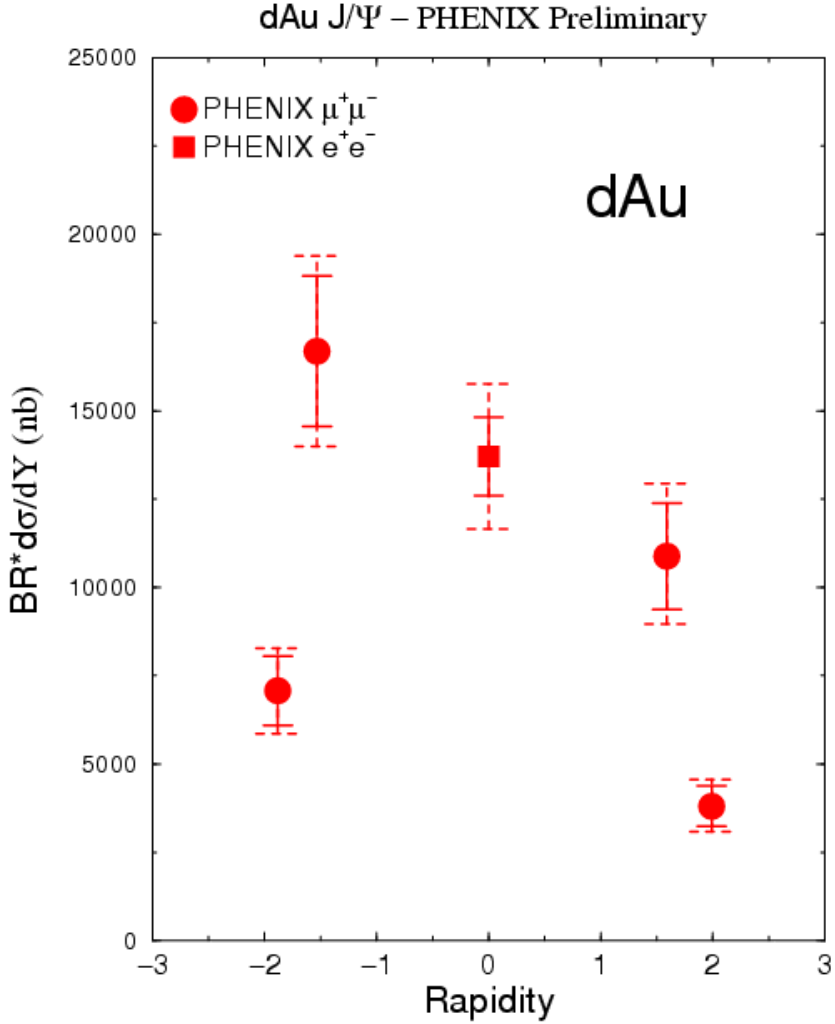


Low x_2 ~ 0.003

High x_2 ~ 0.09

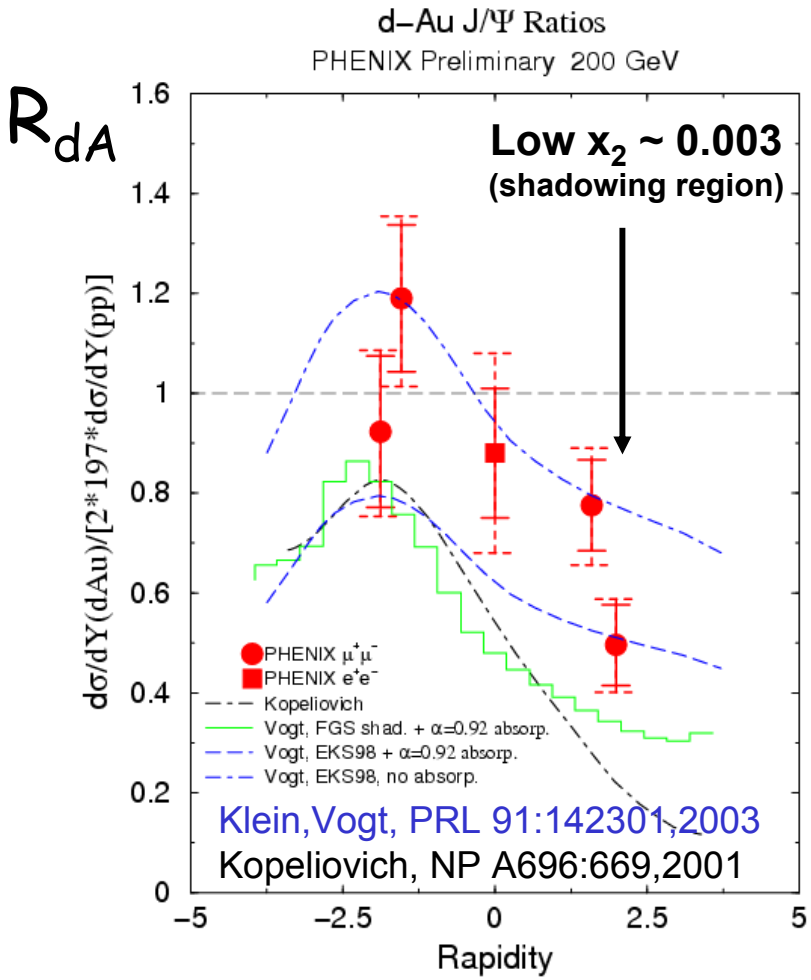
Cross section versus rapidity

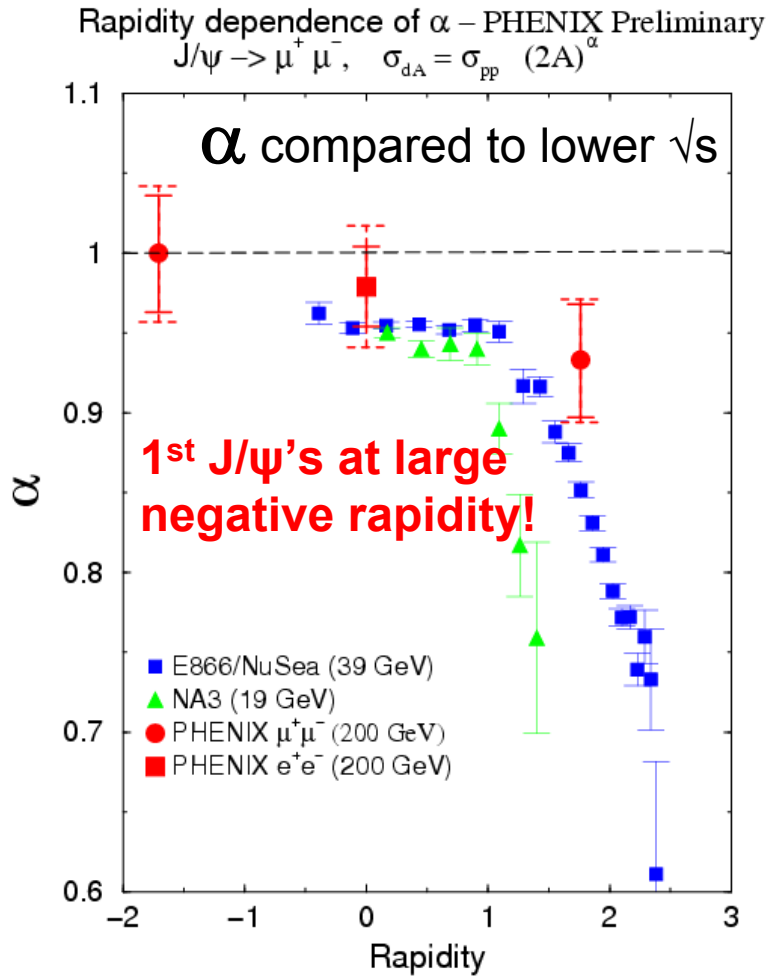




BR $\sigma_{pp}^{J/\psi}$ = 160 nb ± 8.5 % (fit) ± 12.3% (abs) - preliminary

dAu/pp versus rapidity





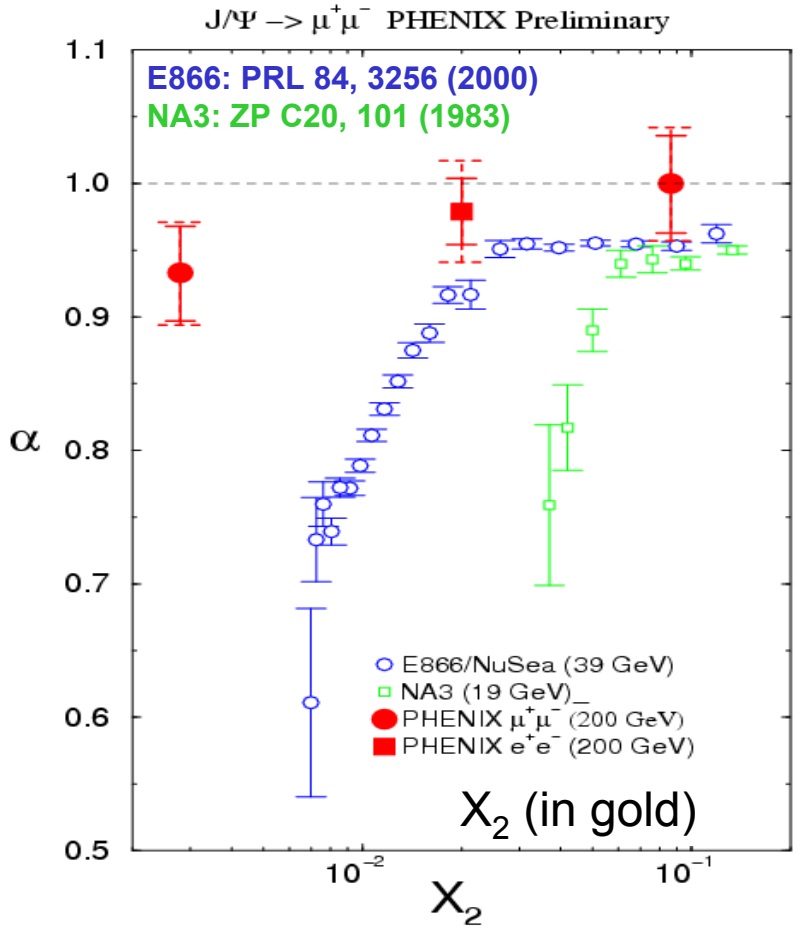
Data favors (weak) shadowing + (weak) absorption ($\alpha > 0.92$)

With limited statistics difficult to disentangle nuclear effects

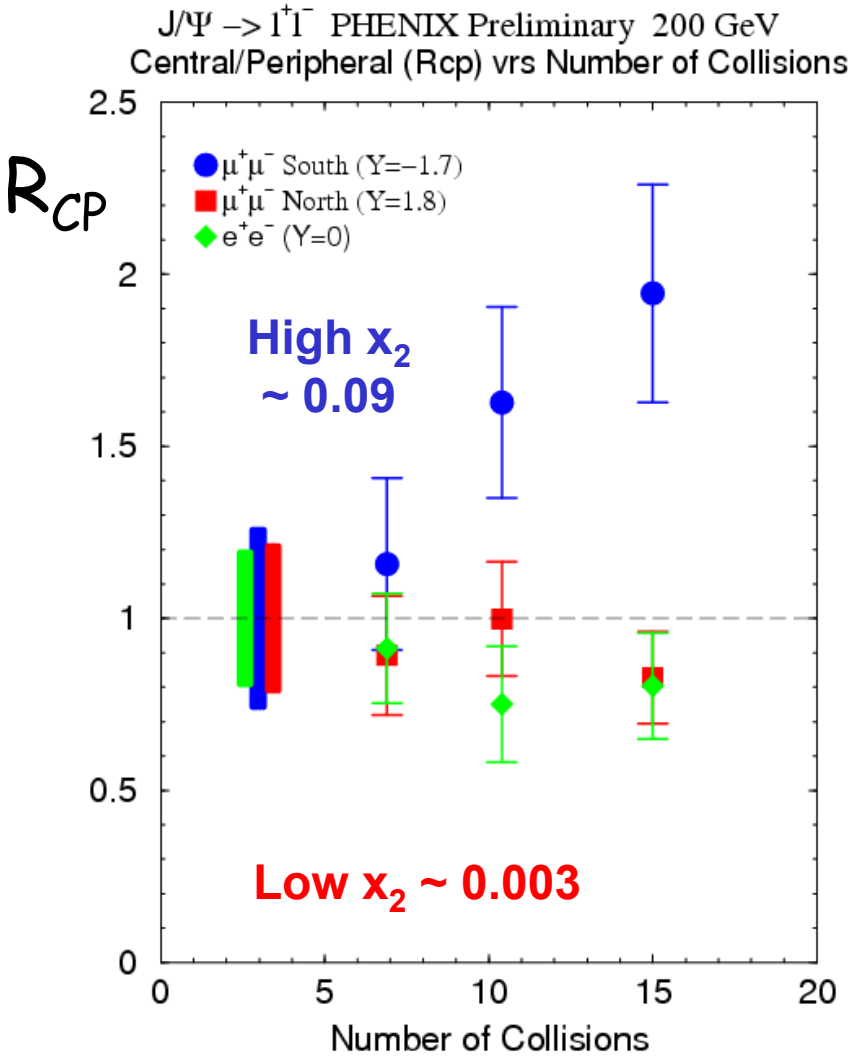
Will need another dAu run! (and more pp data also)

α versus $x_2(x_{Au})$ compared to lower $\sqrt{s}$

- Not universal versus X_2 : shadowing is not the whole story.
- Energy loss expected to be weak at RHIC energy
- But could it explain larger suppression for lower energy data?



Central/peripheral versus N_{coll}

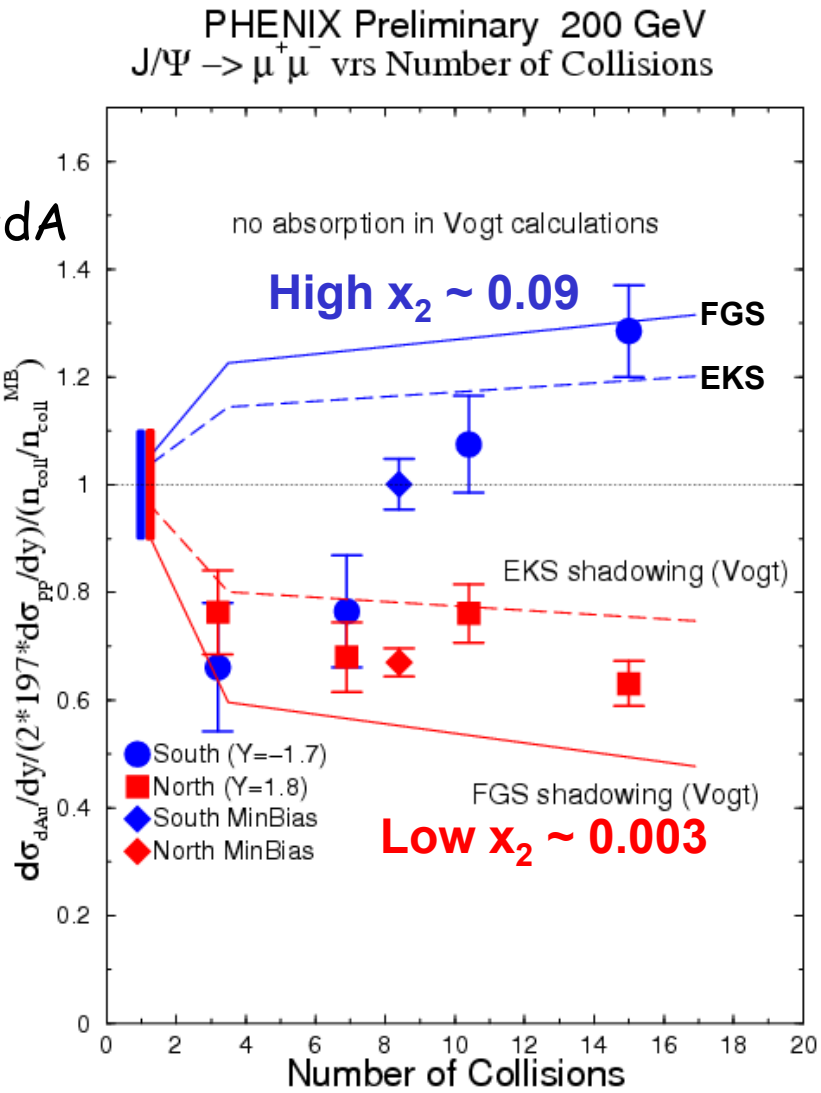


$$R_{cp}(N_{coll}) = \frac{N_{J\psi}^{cent} \times < N_{coll}^{periph} >}{N_{J\psi}^{periph} \times < N_{coll}^{cent} >}$$

- Low and med x_2 have small variations
  - Weak nuclear effects
  - Small shadowing centrality dependence
- High x_2 has a steep rising shape
  - Difficult to see how antishadowing could be so steep when shadowing is not?

dAu / pp versus N_{coll}

R_{dA}



$$R = \frac{\sigma_{dA} \times < N_{coll}^{MB} >}{2 \times 197 \times \sigma_{pp} \times < N_{coll} >}$$

- Low x_2 shape consistent with shadowing models
- High x_2 shape steeper than corresponding antishadowing…
  - What could it be ?
  - Effect of being closer to the Au frame ?
  - e.g. final-state effects in Au nucleus remanant?

Open Charm Physics

Charm production (D mesons) is complementary to J/ψ studies

- shares the same initial-state effects - production mechanism, shadowing, p_T broadening
- but is different in the final-state – e.g. absorption only for J/ψ, final-state p_T broadening…

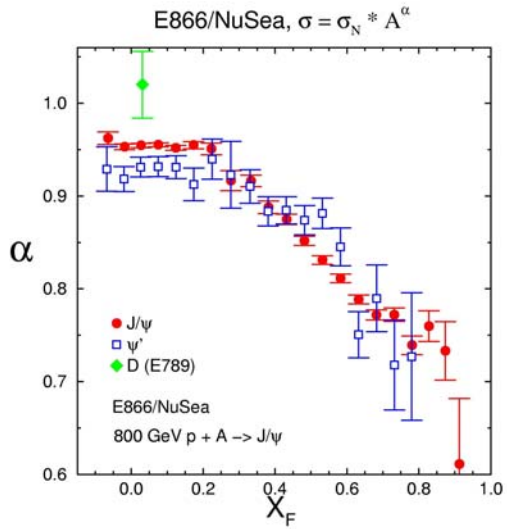
Open charm has little or no nuclear dependence in the mid-rapidity (non shadowing) region:

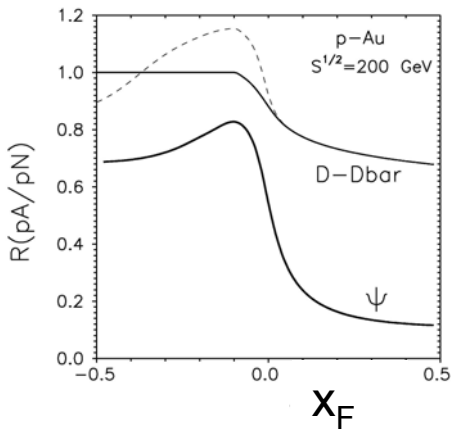
a = 1.00± 0.05	(E769 250GeV p+A)
a = 0.92 ±0.06	(WA82 340GeV p+A)
a = 1.02 ±0.03 ±0.02	(E789 800GeV p+A)

But significant nuclear suppression is reported in the large x_F (shadowing) region (WA78, a=0.81 ± 0.05) which could be due to nuclear shadowing.

Ordinary shadowing is process independent and is a "property" of the structure function in a nucleus but Kopeliovich (*hep-ph/0104256 & hep-ph/0205151)* predicts a large difference between open-charm and J/ψ shadowing

PHENIX will look for this in d-Au measurements by comparisons between open- and closed-charm.

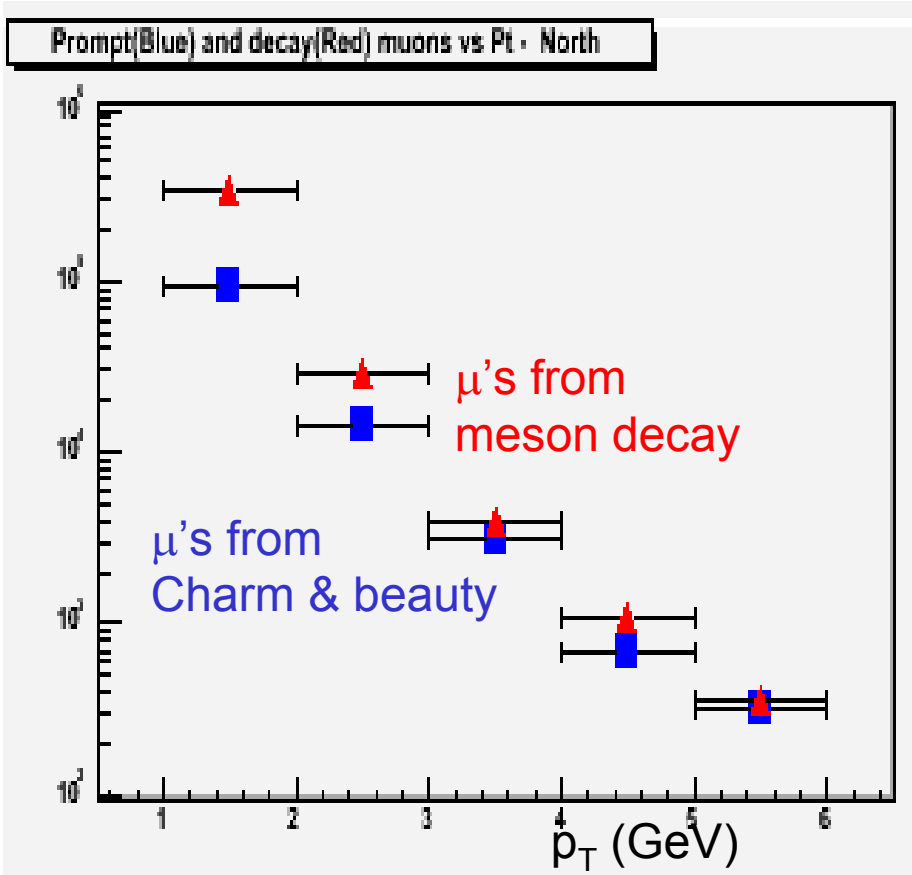




Open charm from single muons coming soon…

The PHENIX Muon arms give the **only** capability for open charm at RHIC in the (low x) shadowing region!

- A large prompt component in the single muon spectra (in blue in figure) contains a large open charm signal. Work is in progress to correct it for significant contributions from hadron punch through.
- Open charm in dAu collisions at mid-rapidity does not show any suppression, i.e. scales with #collisions from pp.

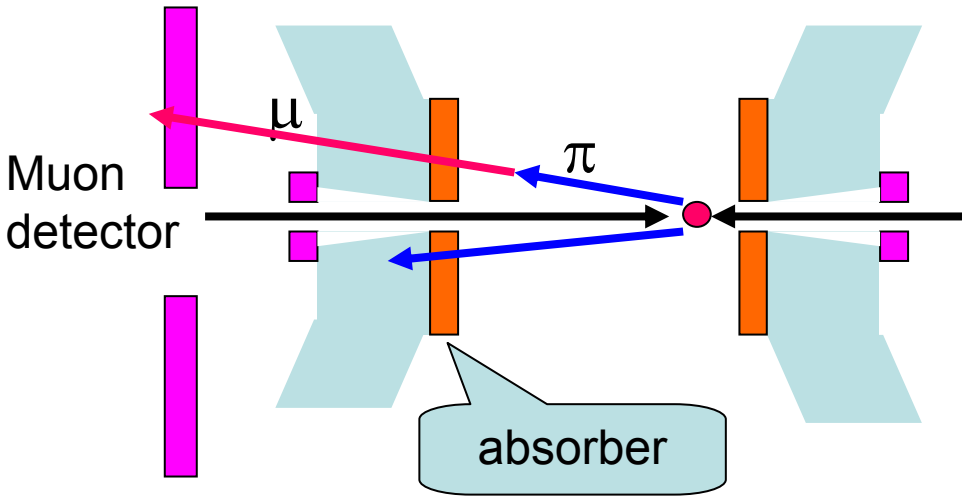


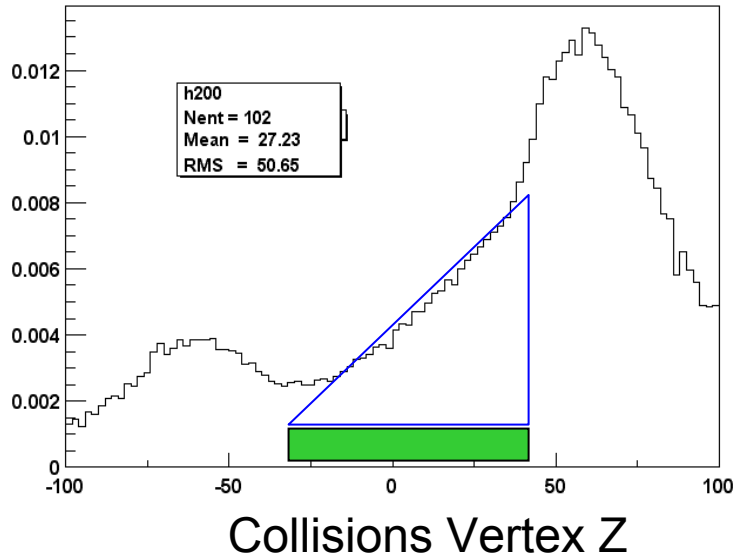
Analysis led by LANL (Ming Liu)

But muon backgrounds from Light Meson Decays are also a signal : forward hadrons from muons

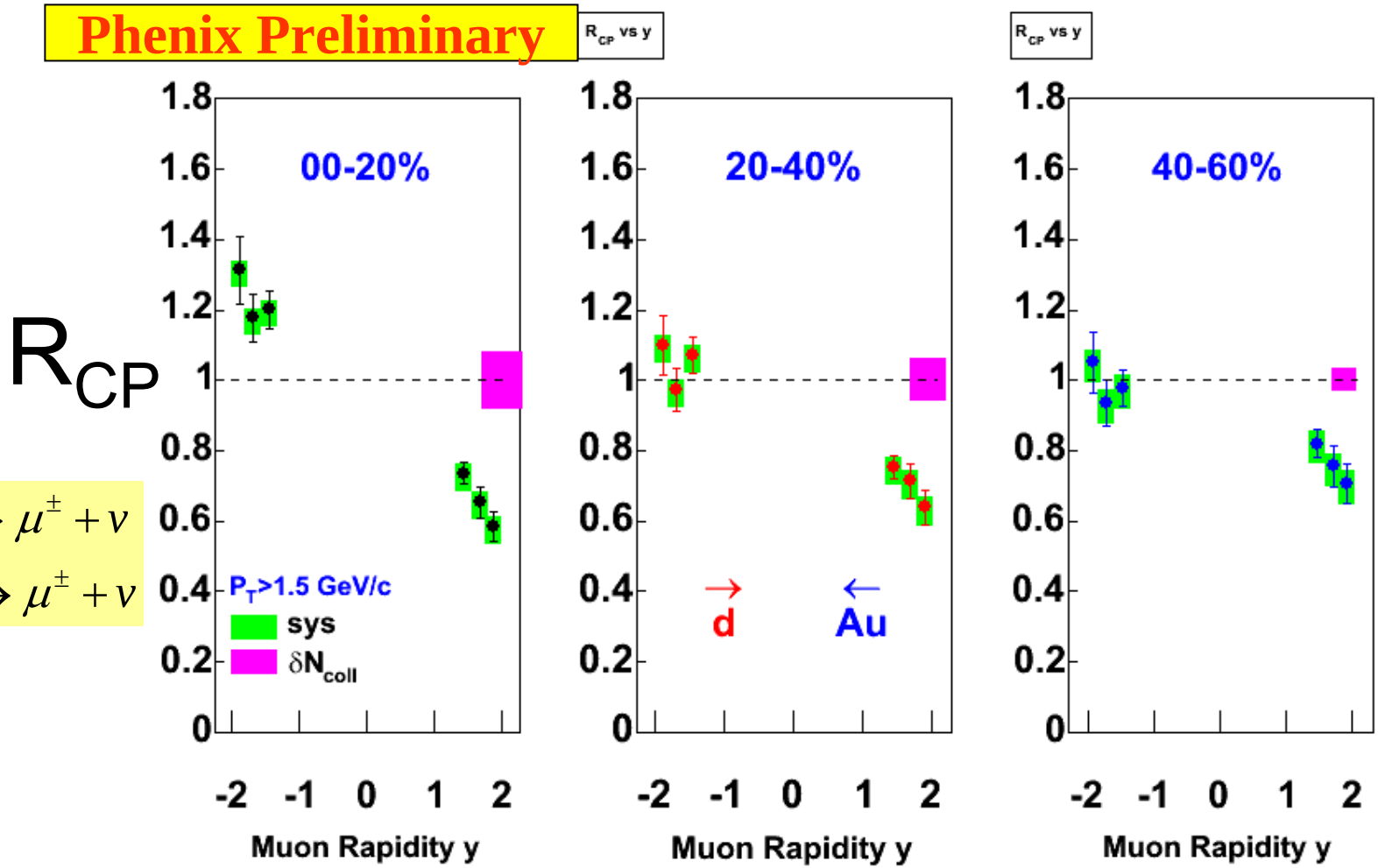
(or one man's background is another man's signal….)
Ideas from & Analysis led by LANL (Ming Liu)

- Separation from prompt muons via event collision vertex distribution





R_{CP}(y): Muons from Light Meson Decays



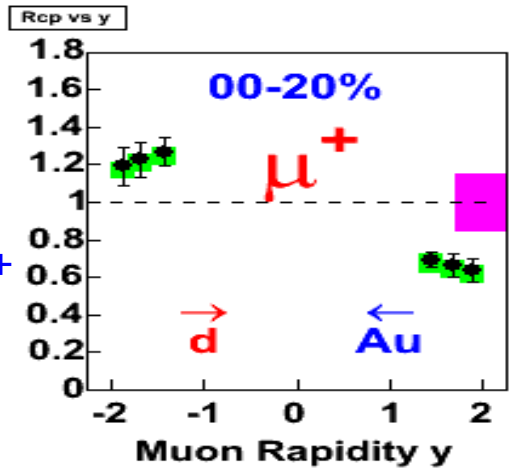
$\pi^{\pm} \rightarrow \mu^{\pm} + \nu$

$K^{\pm} \rightarrow \mu^{\pm} + \nu$

$R_{CP}(y)$: Muons from Light Meson Decays

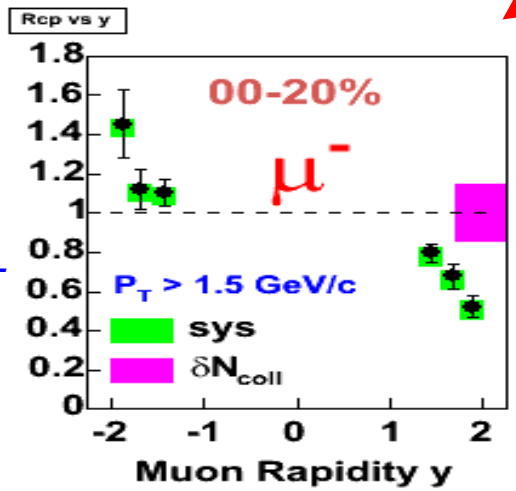
Phenix Preliminary

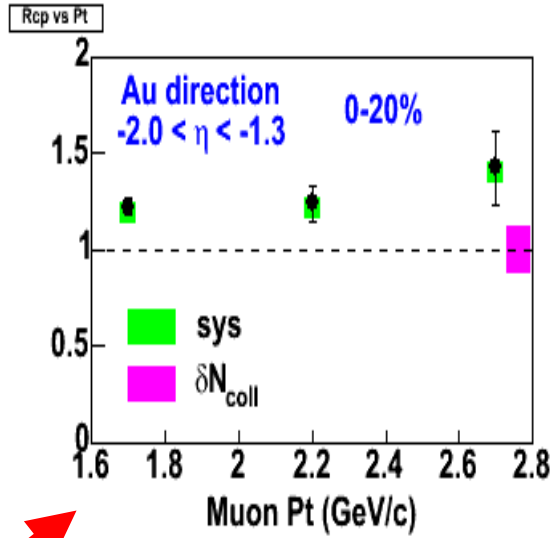
Rcp π^+, K^+



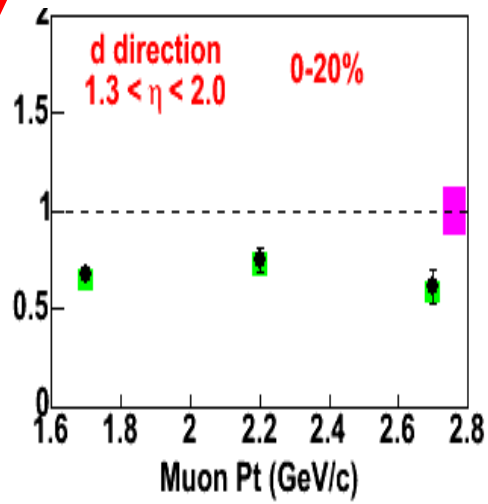
Little Charge Dependence (no obvious leading parton effect?)

Rcp π^-, K^-



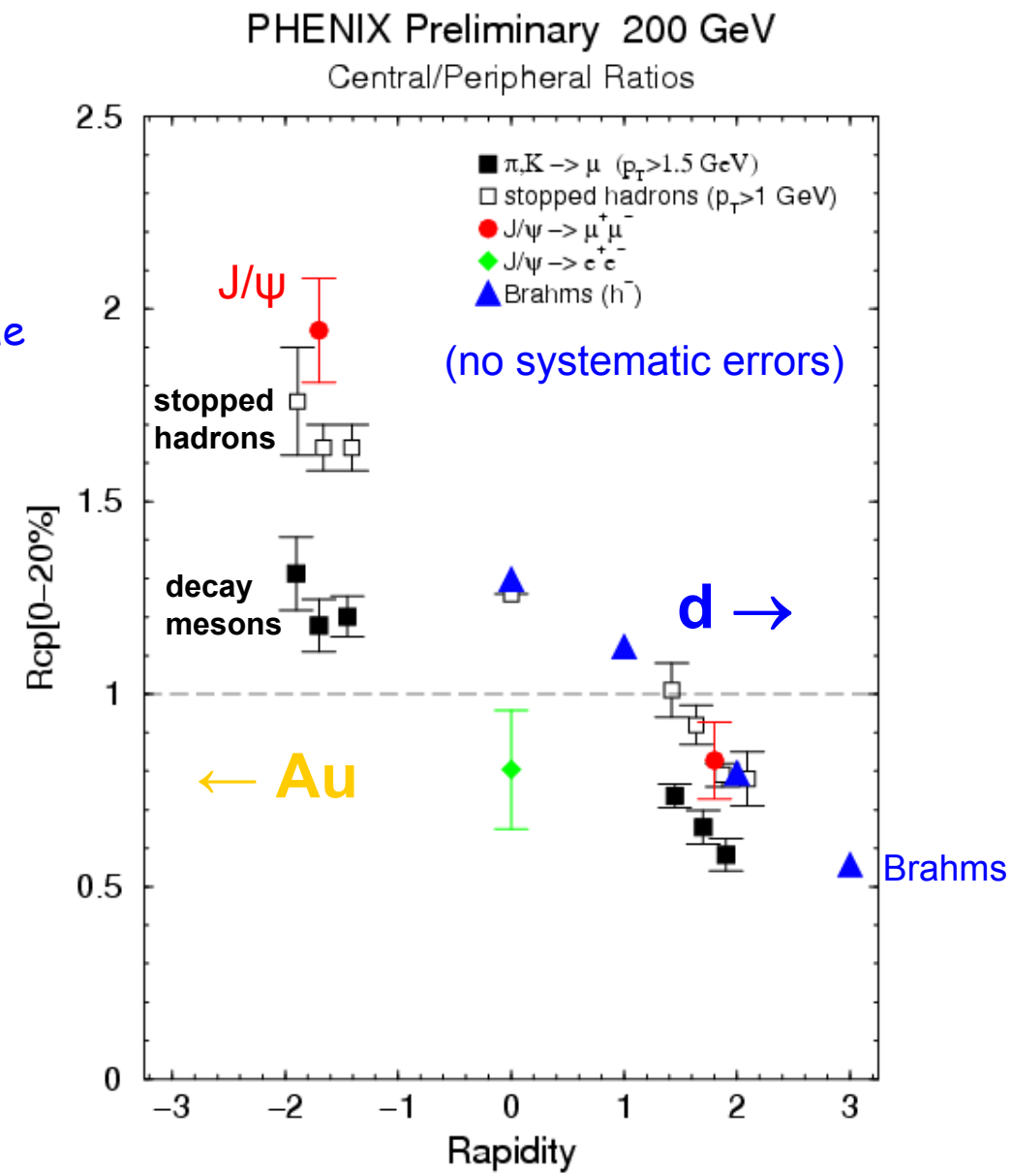


Flat p_T dependence



Let's Compare centrality dependence of light mesons (π,K) or hadrons and J/ψ's

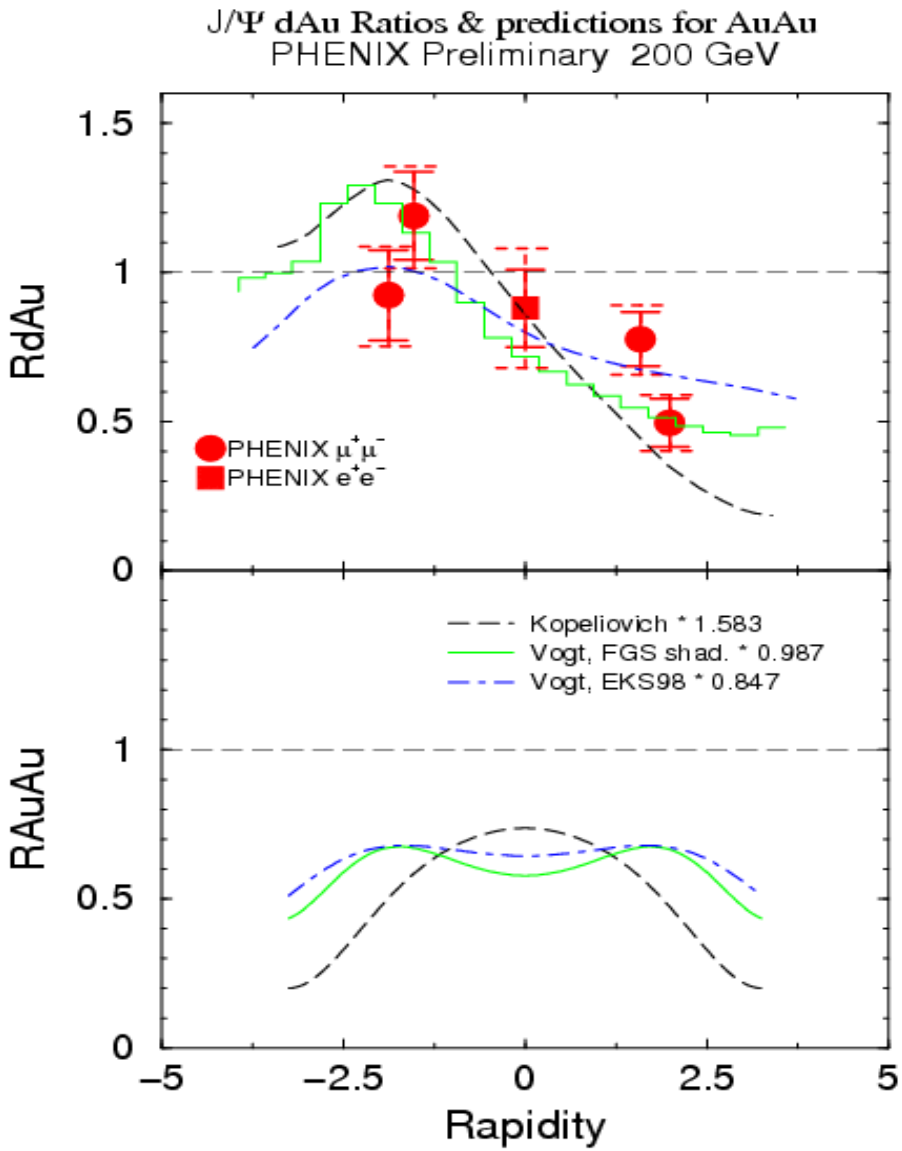
- J/ψ's have similar trends but
  - a smaller effect in the shadowing region
  - and much stronger effect in the Au direction
- p_T>1.5 GeV/c (π,K) or > 1 (hadrons) might cause some differences from J/ψ
- production mechanism differences:
  - J/ψ : gluon fusion
  - hadrons : quark-gluon ~ gluon-gluon with former dominating at higher p_T
- particle mix differences
  - decays are only π & K (π/K ~1)
  - hadrons include protons (p/π ~ K/ π ~ 0.3)
- Kharzeev thinking about Au gluon field enhancement of J/ψ production as explanation for large effect at negative rapidity



Simple expectation for AuAu J/ψ's based on nuclear dependence observed in dAu

- Renormalize model predictions to dAu measurement (top panel).
- Then reverse RdAu and multiply by itself (bottom panel)
- Variations between models not too large at mid-rapidity, but substantial in the large negative or positive rapidity regions. Better models (physics understanding) might help, but a higher statistics dAu baseline, especially in the μμ regions is needed.

- 2004 AuAu run: (1600 J/ψ)/arm expected for 130 μb^{-1}
- Challenge of pulling out J/ψ signal in AuAu now being worked!



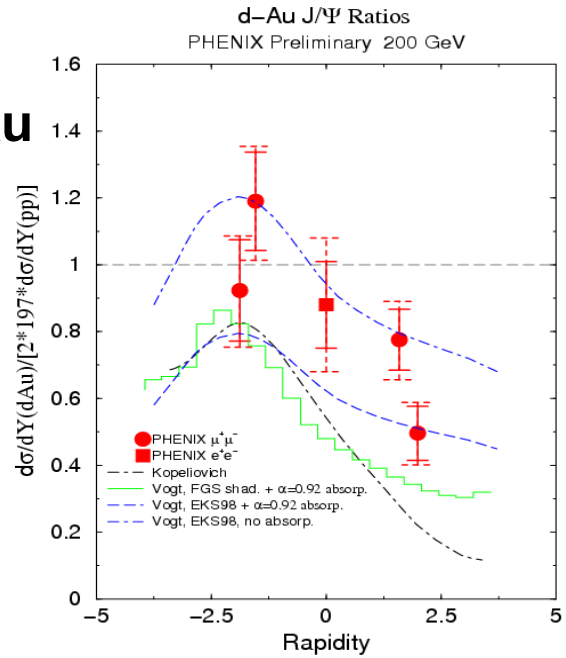
Other Physics Goals for the Future

- Some other future LANL focuses in the pp, dAu area:
  - angular distibutions for J/ψ to try to determine production mechanism
  - J/ψ and other signals vrs reaction plane, e.g. to better isolate final-state effects
  - ψ′ as a cleaner physics window into shadowing and other nuclear effects (the ψ′, unlike the J/ψ, has no feeddown from higher mass resonances)
  - open beauty from single muons at higher p_T
  - ϒ production and its nuclear dependence
  - more exclusive studies of heavy-quark production using a silicon vertex upgrade
- Most of these require higher luminosity running for dAu along with similar pp runs for comparison.
- Many more details of the overall (PHENIX) plan in the PHENIX 10-year plan (pA sections written mostly by yours truly)

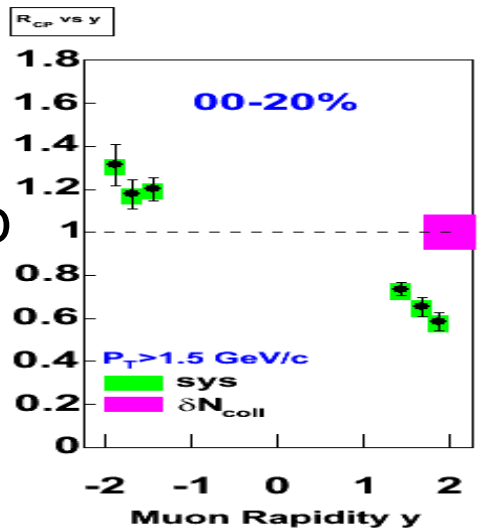
Summary

- dAu J/ψ data suggests that gluon shadowing is weak and that absorption is smaller than expectations based on lower energy data; and p_T broadening is very similar to that seen at lower energies
- We will need more J/ψ's to definitively disentagle these effects. Another dAu run with higher luminosity is needed.
- Open-charm results at forward and backward rapidity will be coming from the muon analysis soon and will shed further light on the gluons and their shadowing
- Near the Au frame, at negative rapidity, a dramatic centrality dependence in both J/ψ and hadrons has been observed and challenges theoretical models
- LANL is leading the Muon related analysis efforts (e.g. dAu J/ψ and forward/backward hadrons)

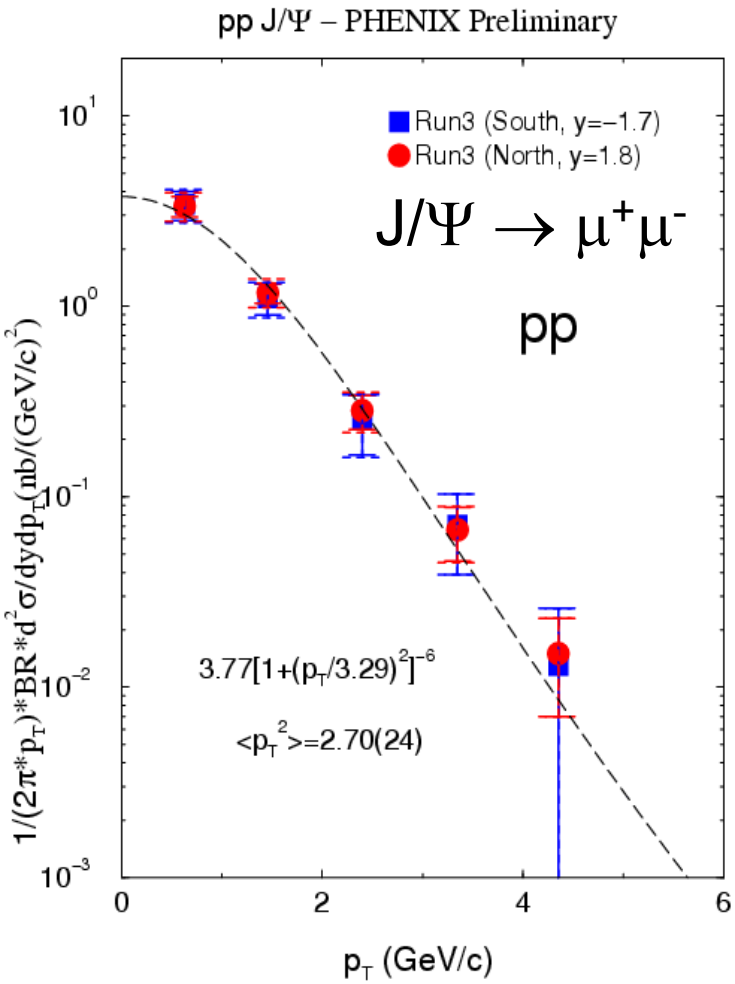
RdAu

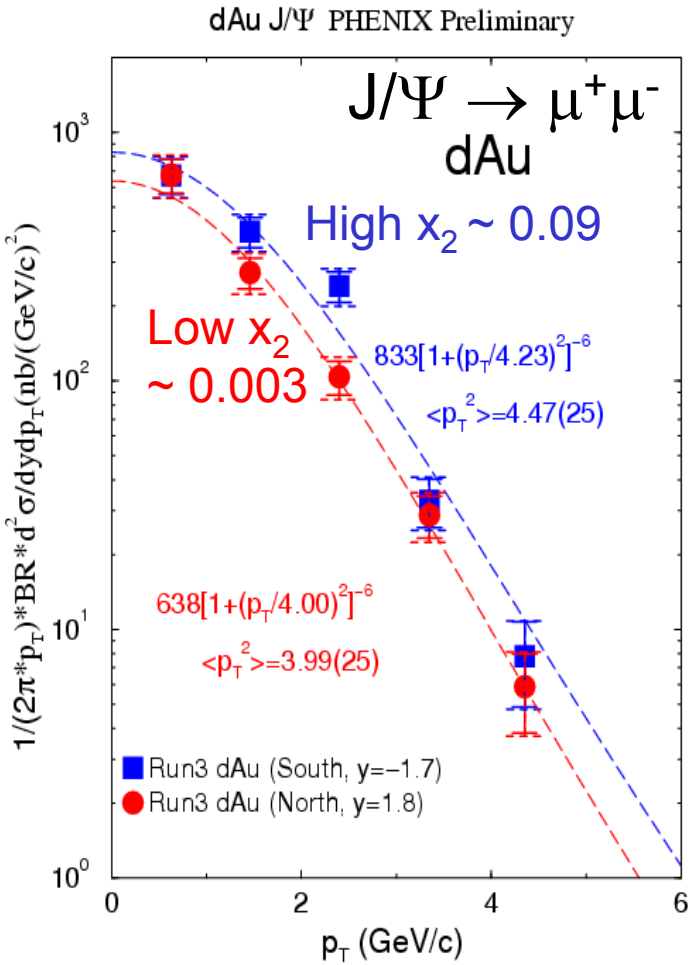


Rcp



Cross section versus p_T





$\Delta\langle p_T^2\rangle =$

$\langle p_T^2\rangle_{dAu} - \langle p_T^2\rangle_{pp}$

1.77 ± 0.35 GeV^2

1.29 ± 0.35 GeV^2

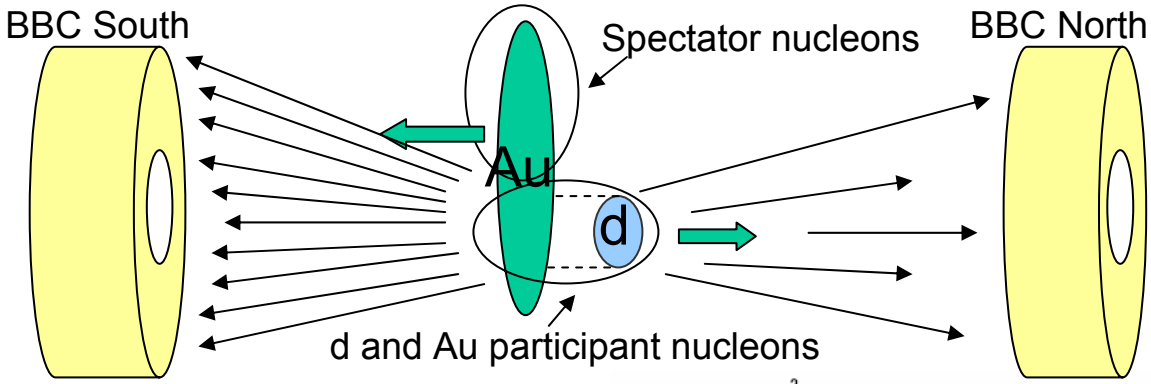
(preliminary)

p_T is broadened for dAu

Centrality analysis

Led by LANL (Jane Burward-Hoy & Mike Leitch)

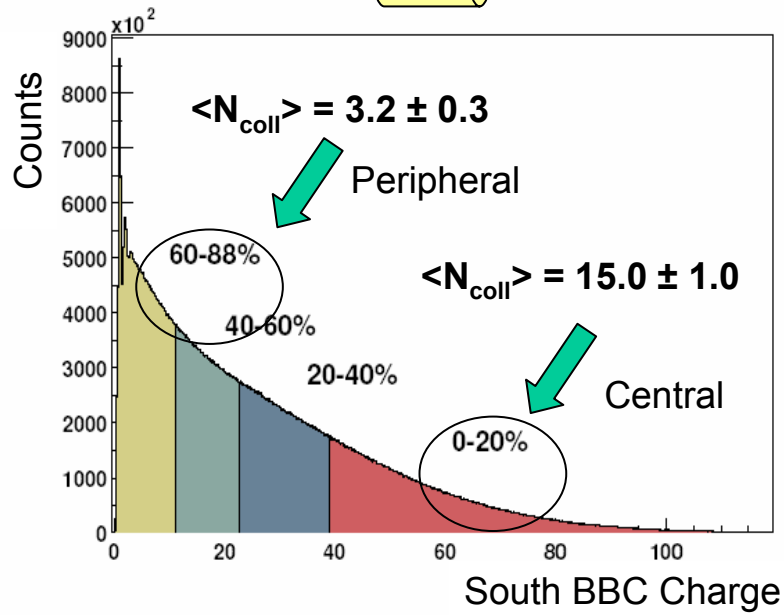
Au breaks up in our south beam counter



- Define 4 centrality classes
- Relate centrality to $\langle N_{coll} \rangle$

through Glauber computation

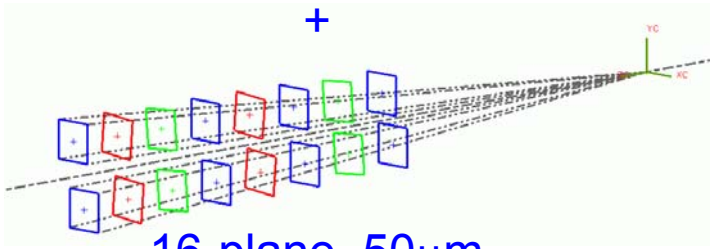
- $\langle N_{coll}^{MB} \rangle = 8.4 \pm 0.7$



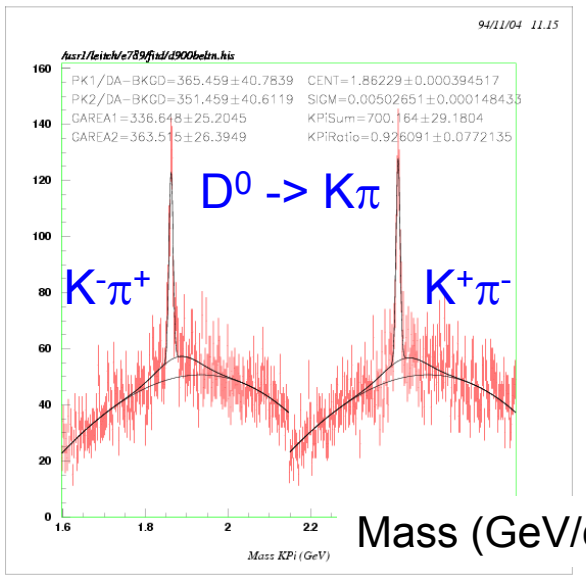
Fermilab E789: D^0 & B → J/ψ X
(experience with charm & beauty using silicon)

Dimuon spectrometer

+



16-plane, 50μm
pitch/8.5k strip silicon
vertex detector



Mass (GeV/c^2)

B -> J/ψ + X